# **DSA** AS A COMPLEMENTARY TECHNIQUE FOR **CONTACT HOLE PATTERNING**

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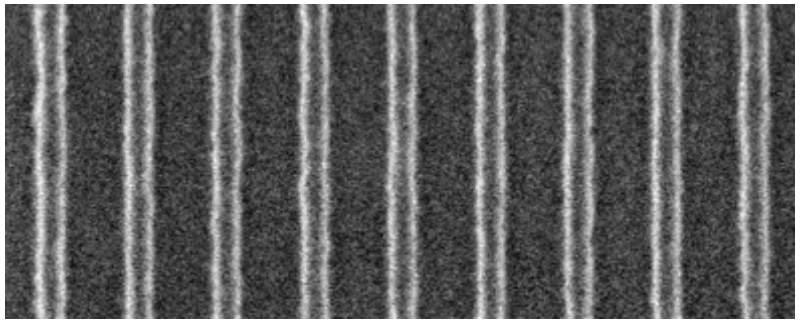
# SCOPE OF THIS TALK

## DSA and EUV:
competing, complementing, enabling ?

*Use case:*

Contact holes patterning using ArFi/EUV pre-patterns followed by a DSA process.

# WHAT IS 'DIRECTED SELF ASSEMBLY' ?



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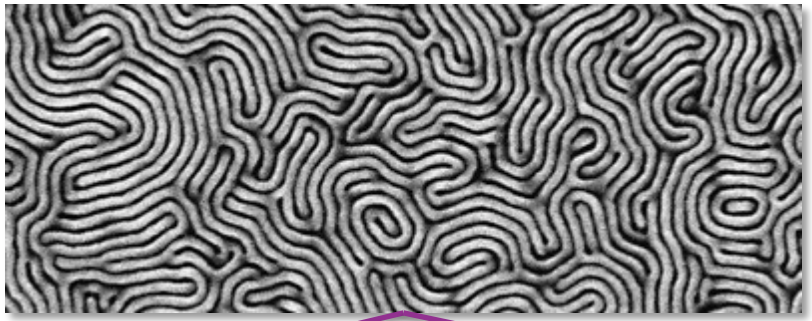
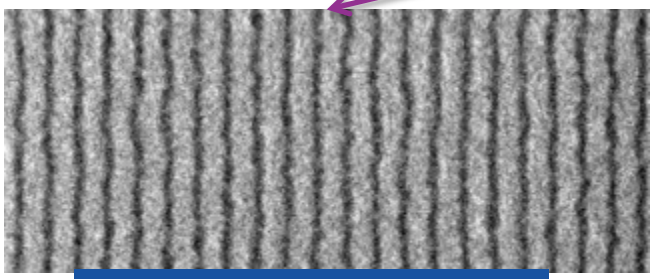
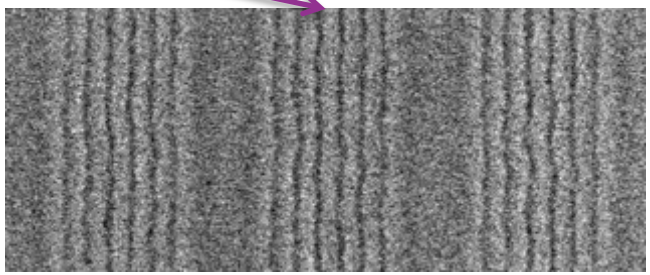




Chemo-epitaxy



Grapho-epitaxy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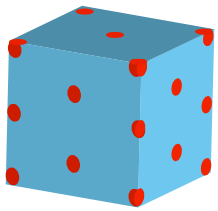
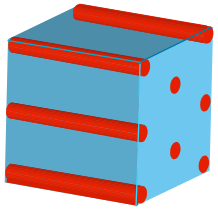
# SELF-ASSEMBLY OF BLOCK COPOLYMERS IN THE BULK

Block Copolymers are macromolecules formed by two or more chemically distinct polymer chains joined by a covalent bond

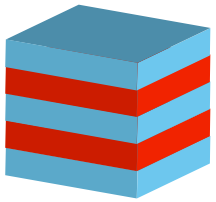
Bulk



Spheres



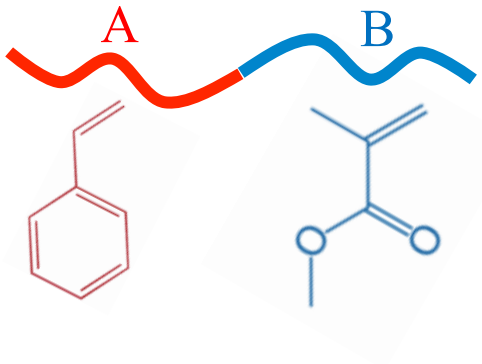
Cylinders



Lamellae

Poly(styrene-*b*-methyl methacrylate)

(PS-*b*-PMMA)

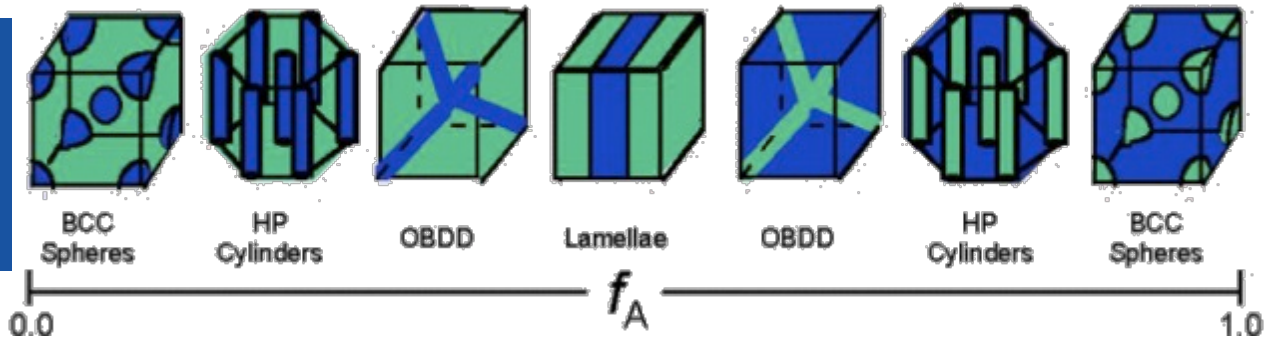



Structures represent thermodynamic minima
Dense features - 3 to 50 nm length scale
How to control 'preferred' feature type, size and pitch ?

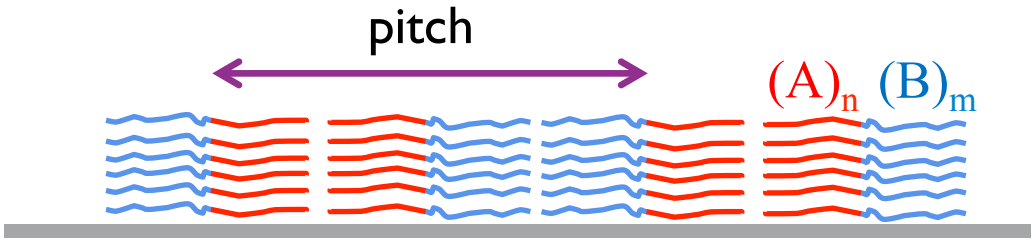
# SELF-ASSEMBLY OF BLOCK COPOLYMERS IN THE BULK

BCP: A and B in separate segments


n/m determines phase
- Lamellar for LS
- Cylinders for CH

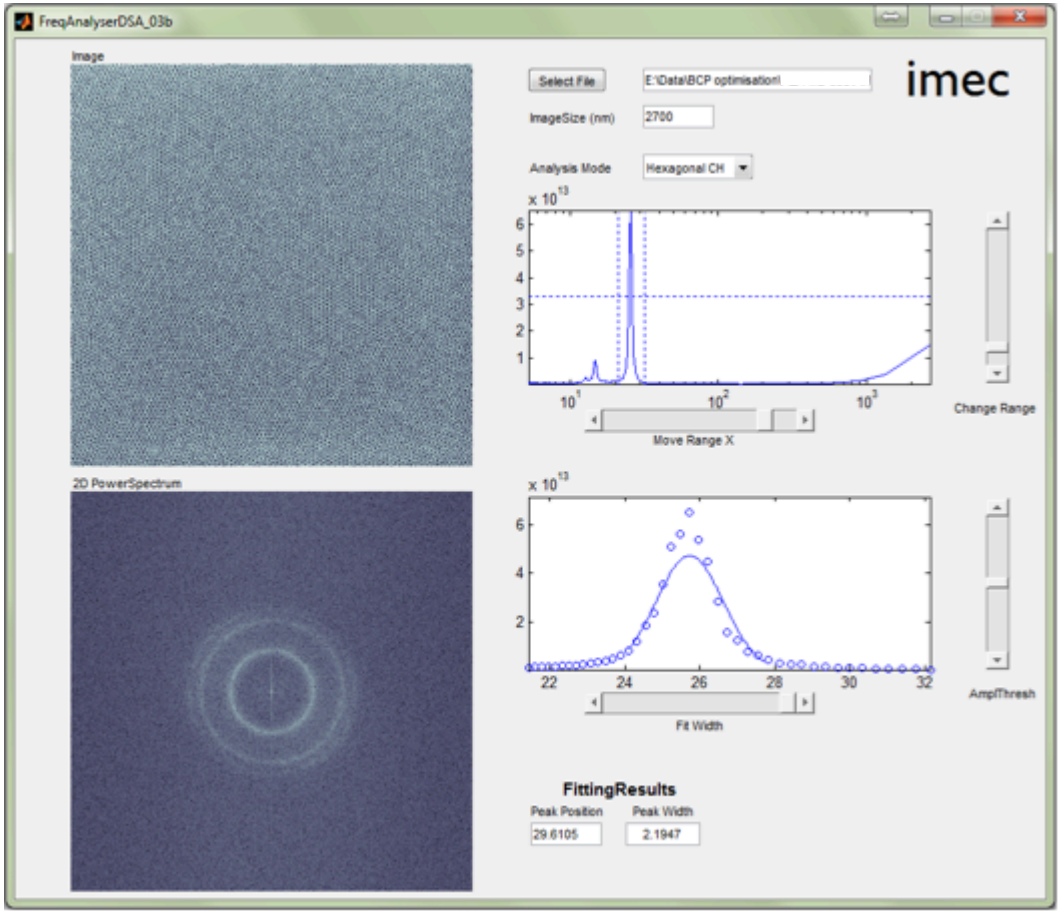



n+m determines
- pitch (and CD)




Feature, CD and pitch are in the bottle – 'Brain in the bottle', ©Ralph Dammel

# FEATURE TYPE AND CD IN THE BOTTLE
## FREQUENCY ANALYSIS




Frequency analysis on self-assembled BCP material allows to determine $L_0$ and check phase separation quality.

# OUTLINE

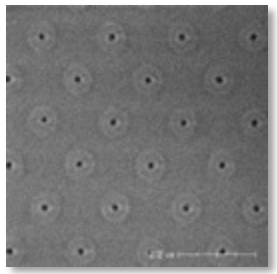
Introduction

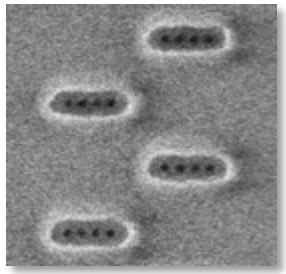
Contact Hole Shrink (grapho-epitaxy)

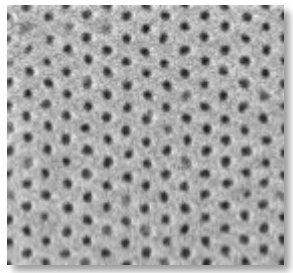
Templated Process (grapho-epitaxy)

Honeycomb Process (chemo-epitaxy)

Summary





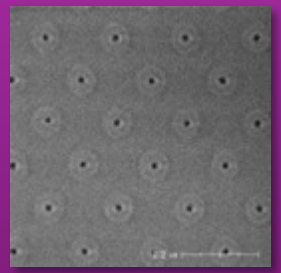


# OUTLINE

Introduction

Contact Hole Shrink (grapho-epitaxy)

- Homopolymer blend and block co-polymer
- Demonstration of electrical functionality



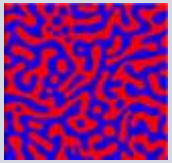
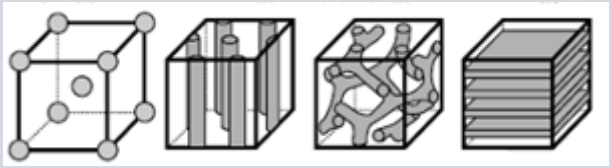
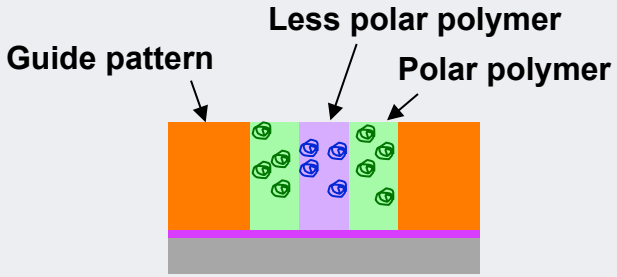
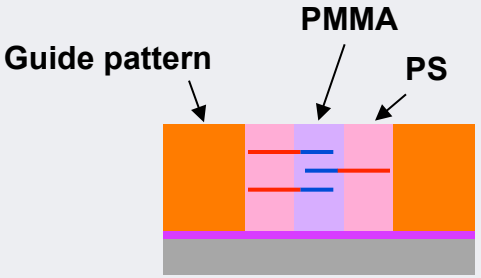
Templated Process (grapho-epitaxy)

Honeycomb Process (chemo-epitaxy)

Summary

# TWO DSA OPTIONS TO COMPARE

## POLYMER BLEND & PS-PMMA BCP

| | Blend type (PolymerA/PolymerB) | BCP type (PS-*b*-PMMA) |
|---|---|---|
| **Polymer phase separation** |  • No specific dimension, morphology, or periodicity |  • Intrinsic dimension and pre-determined morphology |
| **CH Shrink** |   • Polar polymer remains for pattern shrink and less polar polymer is removed |   • PS remains for pattern shrink and PMMA is removed |
| **Development** | • Organic solvent | • Dry development<br>• UV irradiation with polar solvent |
| **Anneal condition** | • 120 -150 °C | • 200 -250 °C |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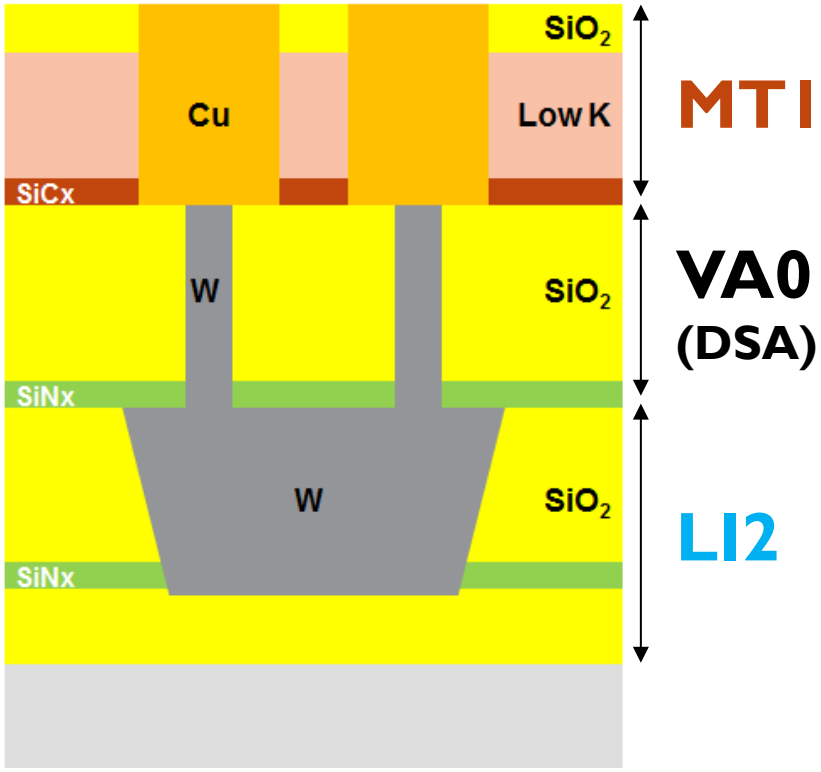
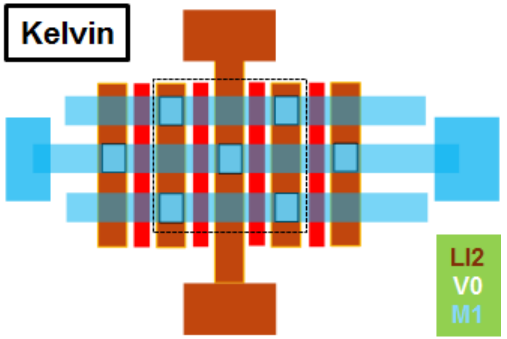
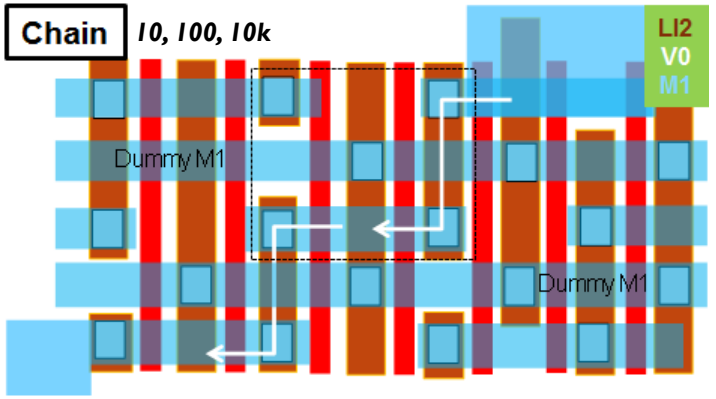
*K. Maruyama, et al. (JSR), 2012 EUVL Symposium*

# EVEREST28 ELECTRICAL TEST VEHICLE

## LI2-VA0-MT1 SHORT LOOP




Want to leverage IMEC's existing 28 nm node infrastructure in order to electrically test VA0 layers built with C/H DSA.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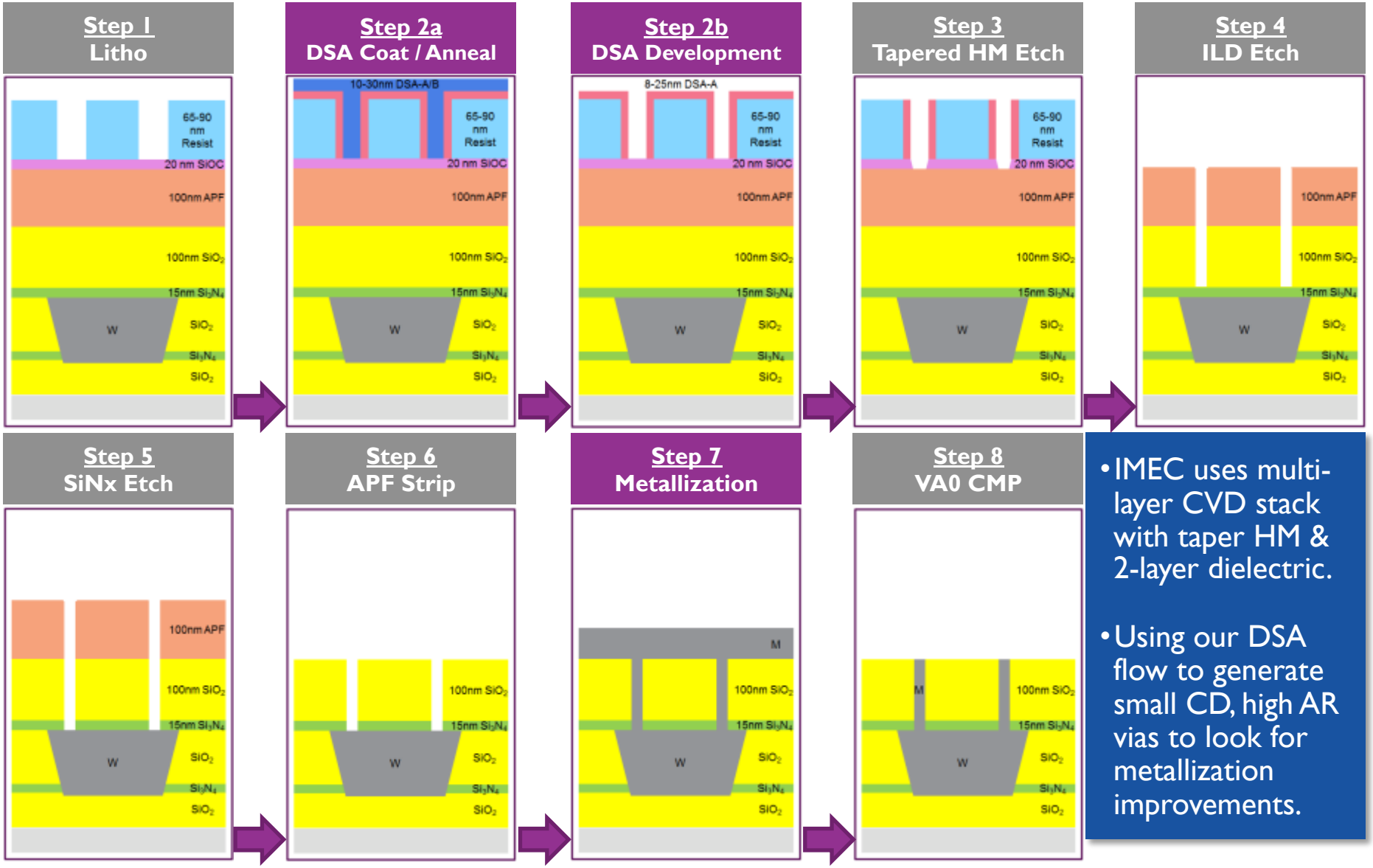
# EVEREST28 ELECTRICAL TEST VEHICLE

## VA0 STACK, DSA, & PATTERN TRANSFER BASED ON IMEC STD PROCESS




- IMEC uses multi-layer CVD stack with taper HM & 2-layer dielectric.
- Using our DSA flow to generate small CD, high AR vias to look for metallization improvements.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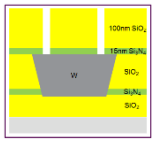
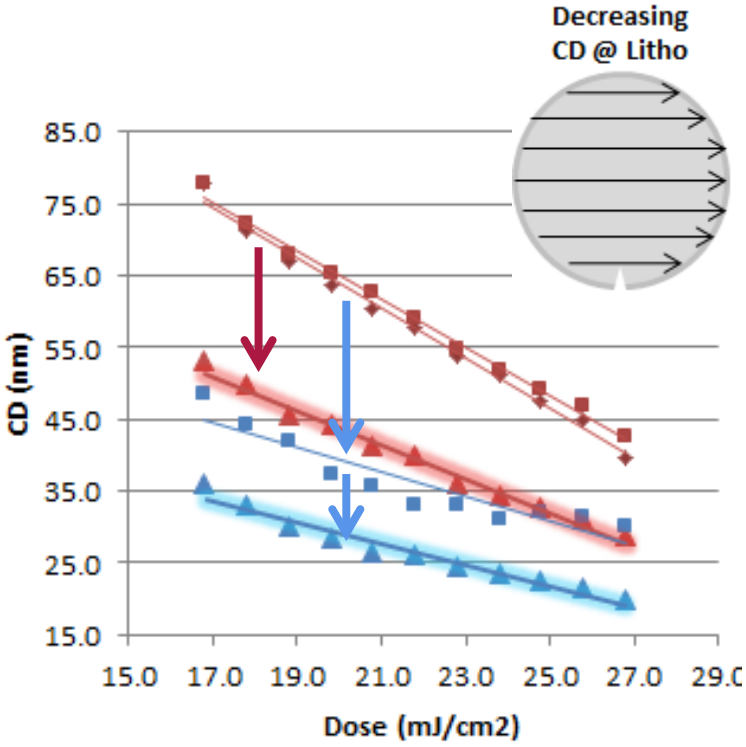
# INTEGRATED PROCESS LOOKS GOOD

## POLYMER BLEND - BEHAVIOR THROUGH DOSE



| Dose | 18 mJ/cm² | 22 mJ/cm² | 26 mJ/cm² |
|---|---|---|---|
| Resist (Only) + Tapered Etch | 53.1 | 39.9 | 28.7 |
| Resist + DSA Blend Shrink + Tapered Etch | 36.0 | 26.2 | 19.9 |




~35% shrink from DSA & ~ 30% shrink from Etch is observed.
Min DSA CD ~ 20-25 nm, post-Etch min CD ~ 20 nm, no missing contacts.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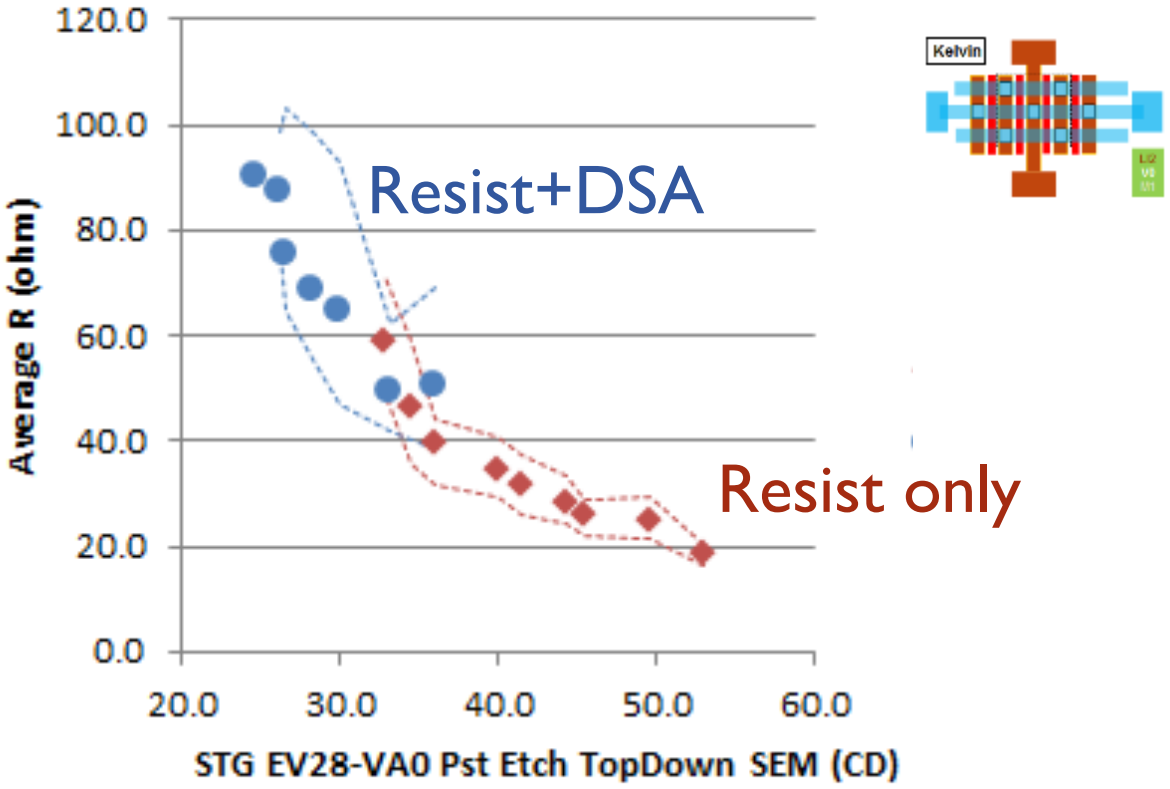
# E-TEST RESULTS BLEND – KELVIN

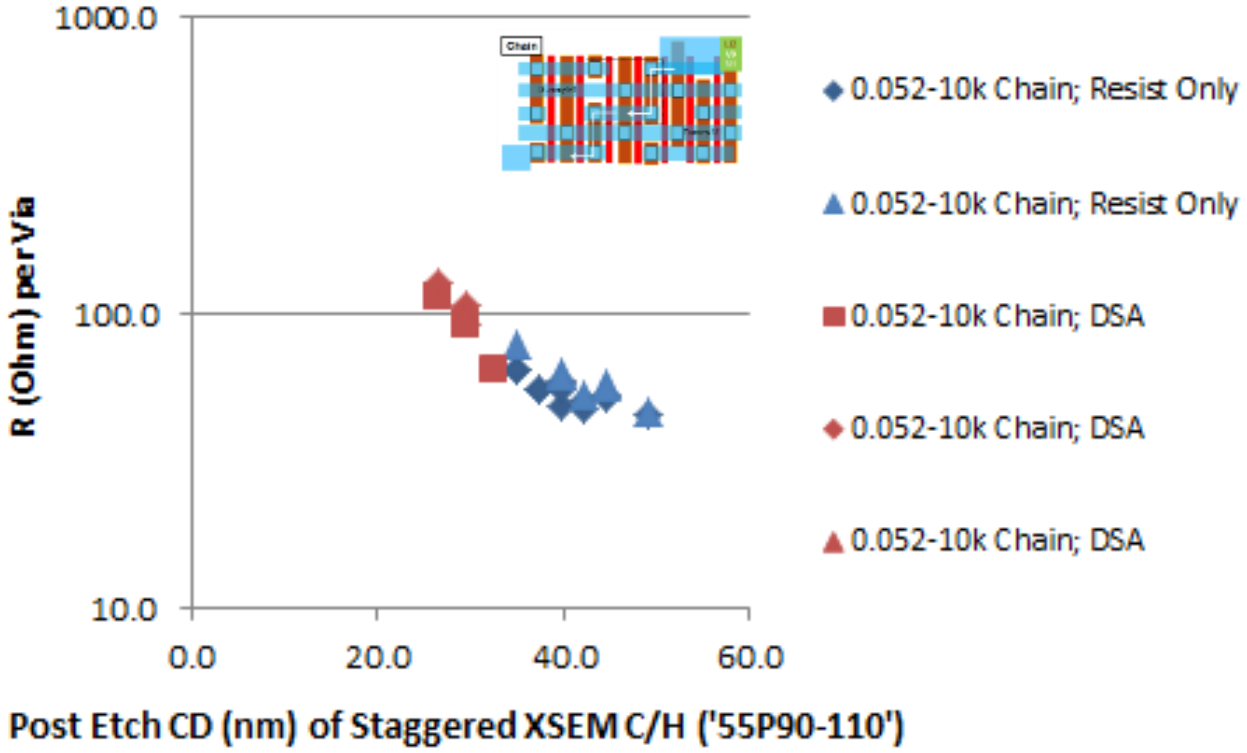
## DSA IS YIELDING! STRONG TREND VS. CD OBSERVED




Excellent match of Resistance vs CD data of DSA-processed structures with litho-only reference. Current limit is ±30nm CD (post-etch)

# E-TEST RESULTS BLEND – 10K CHAIN

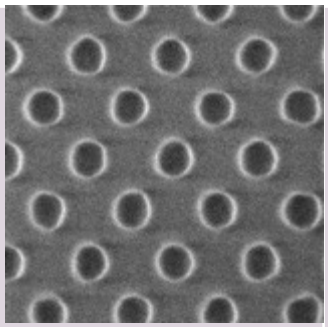
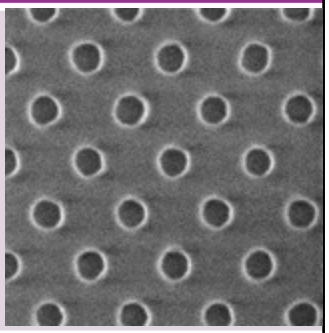
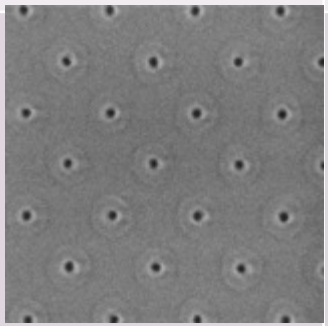
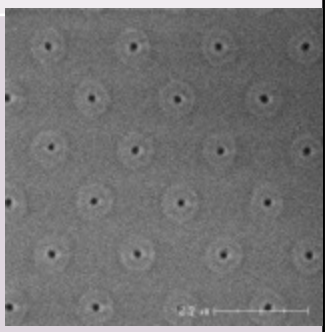
## DSA IS YIELDING! NO STRONG DIFFERENCE BETWEEN DSA/NO-DSA




"It's Alive!" – *Dr. Henry Frankenstein*

# PS-PMMA BLOCK COPOLYMER SYSTEM

## EV28-VA0 BCP DSA

| MASK<br>RESIST<br>SUBSTRATE<br>BCP ($L_0$, nm)<br>PMMA REMOVAL | EV28-VA0<br>GEN 3 GUIDE<br>IMEC CVD + NL<br>BCP-B (~44)<br>WET ETCH | EV28-VA0<br>GEN 3 GUIDE<br>IMEC CVD + NL<br>BCP-C (~33)<br>WET ETCH |
|---|---|---|
| Post-Litho |  |  |
| | 61P90-110 | 54P90-110 |
| Post-Hard Bake,<br>BCP Coat,<br>BCP Anneal, &<br>PMMA Removal |  |  |
| | CD ~ 18 nm<br>CD Shrink ~ 75% | CD ~ 15 nm<br>CD Shrink ~ 73% |

Our BCP Flow Is yielding options for EV28-VA0 CDs < 20 nm

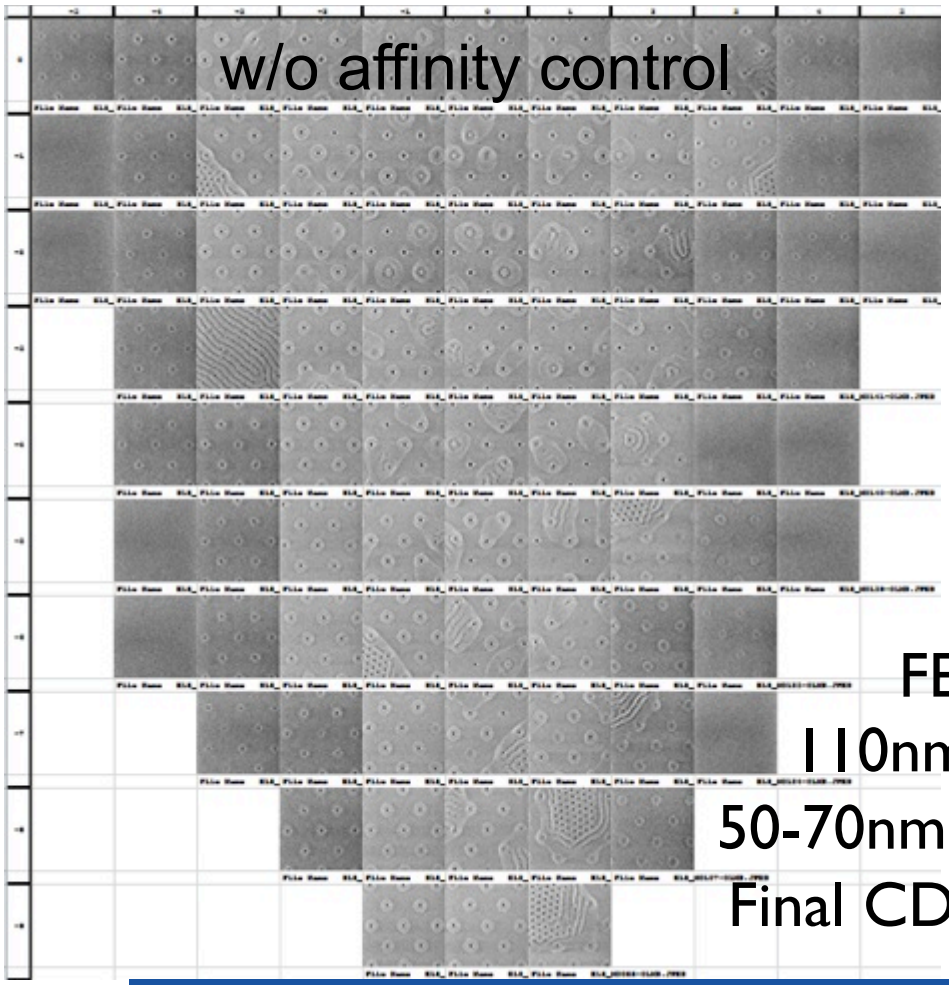
Post-DSA LCDU looks very promising.

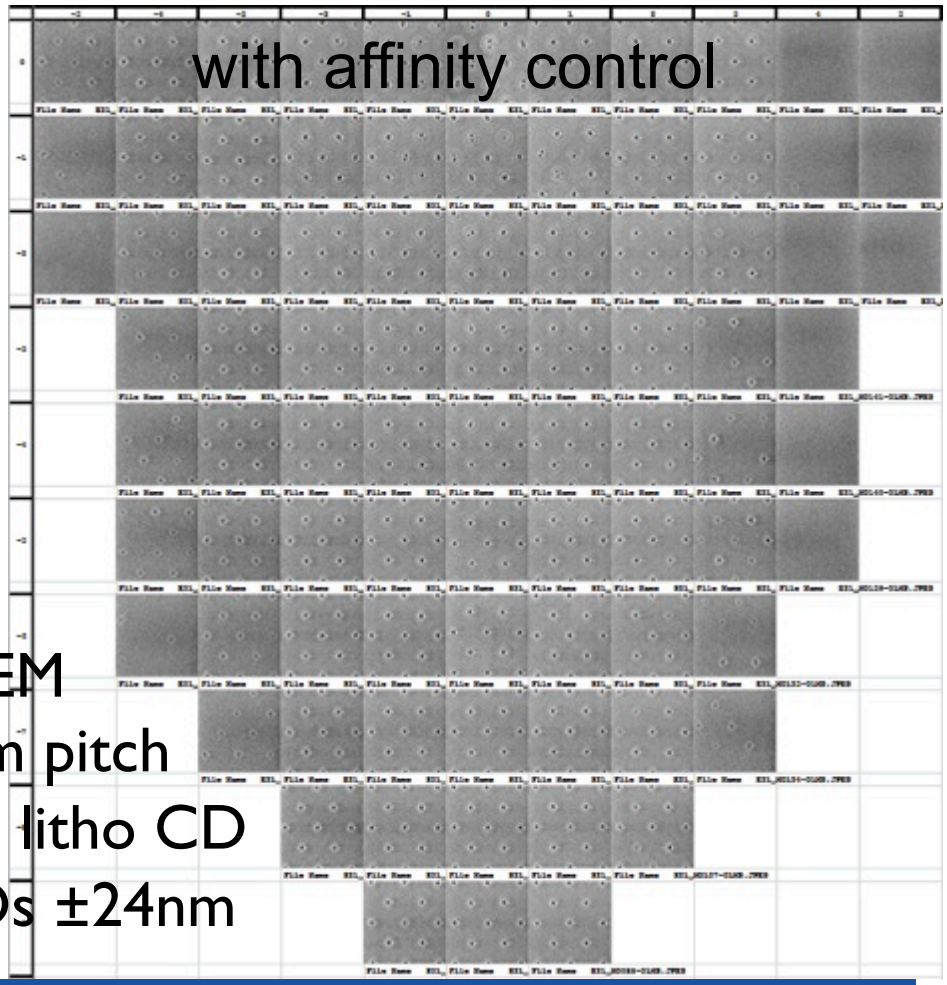
Pattern transfer studies are currently ongoing.

Open hole rate and placement accuracy are main figures of merit for further optimization.

# CH SHRINK USING BCP

## CLOSED CONTACT HOLES ?




FEM

110nm pitch

50-70nm litho CD

Final CDs ±24nm

Surface treatment for affinity control and wet development in TEL track shows a greatly improved 'open contact hole rate'.

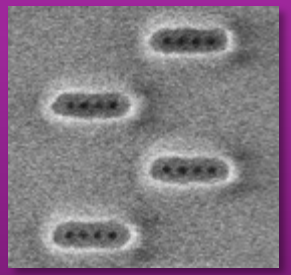
# OUTLINE

Introduction

Contact Hole Shrink (grapho-epitaxy)

Templated Process (grapho-epitaxy)

- Via/cut patterning at sub-EUV resolution

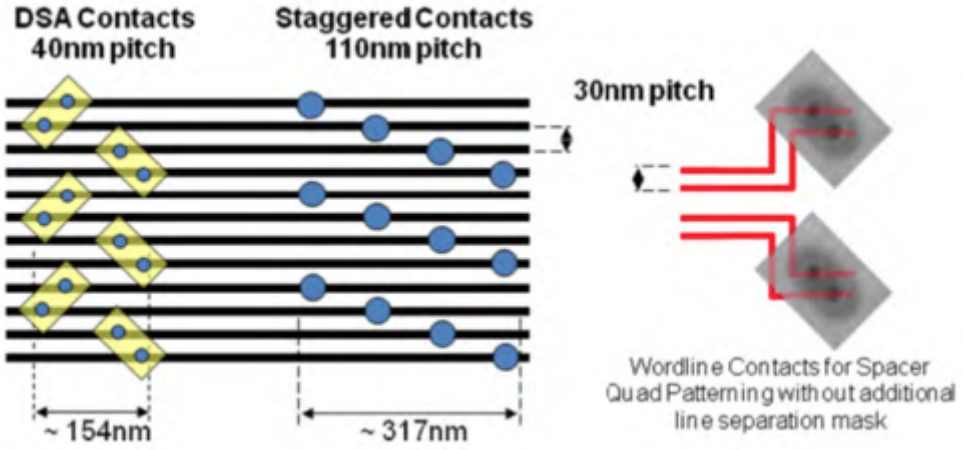


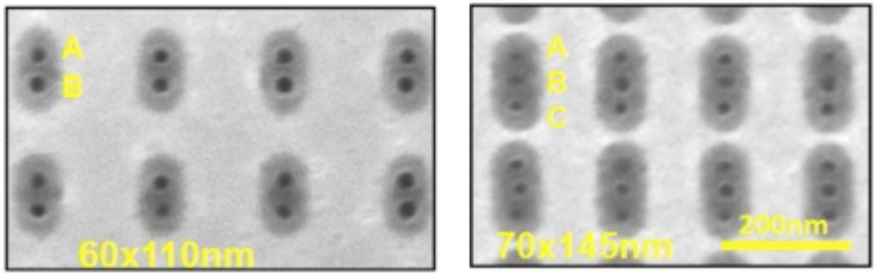
Honeycomb Process (chemo-epitaxy)

Summary

# GRAPHO-EPITAXY FLOW

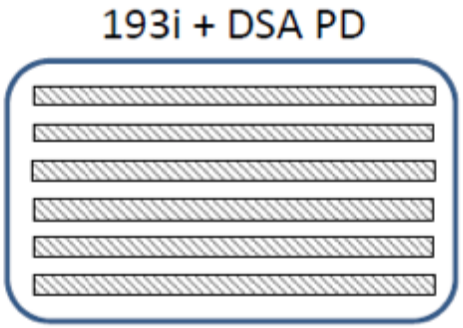
## TEMPLATED DSA FOR HOLE MULTIPLICATION

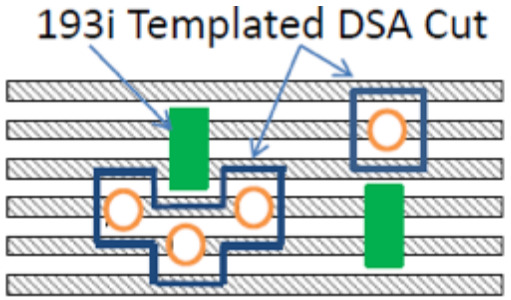



*P.-S. Wong et al. – Stanford/AMAT*

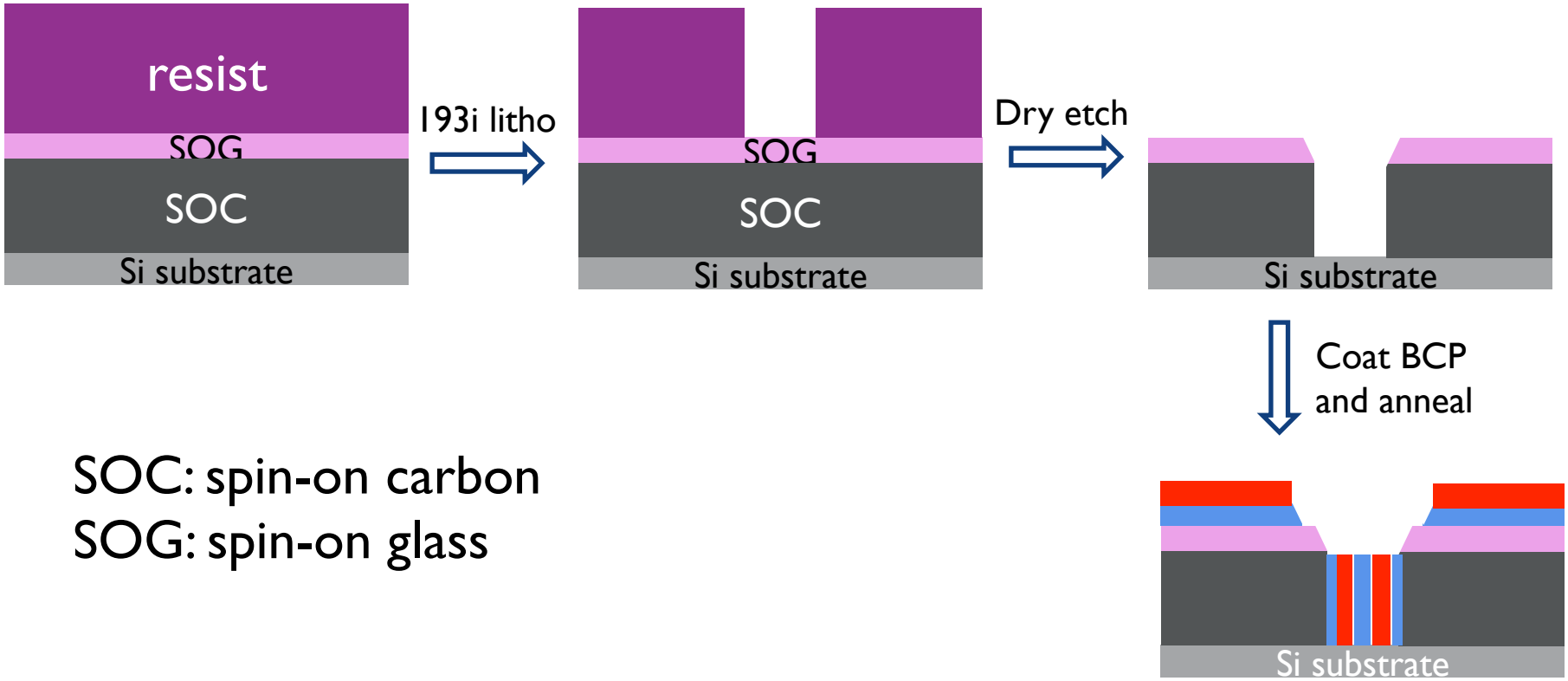
Gridded Layouts –
193i + Pitch Division
+ DSA Cuts
with HVM DSA



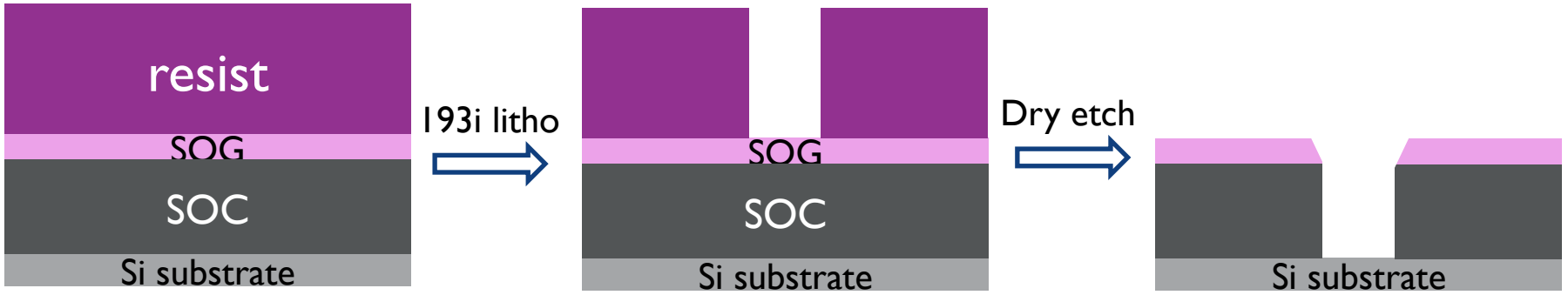

*Y. Borodovsky - Intel*

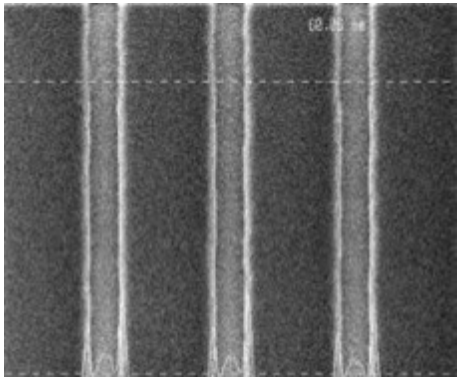
# FLOW FOR TEMPLATED DSA



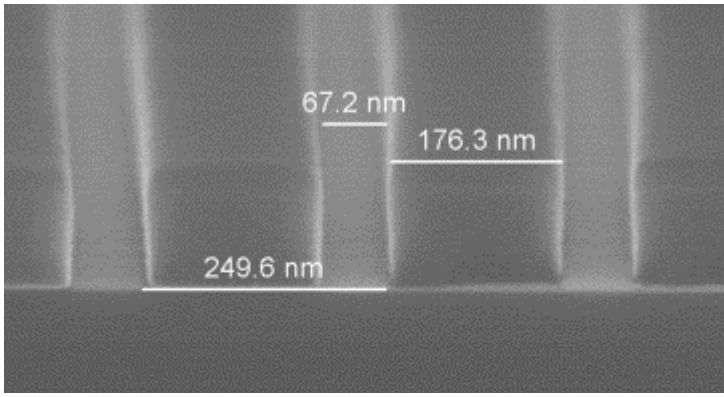

SOC: spin-on carbon
SOG: spin-on glass

# FLOW FOR TEMPLATED DSA



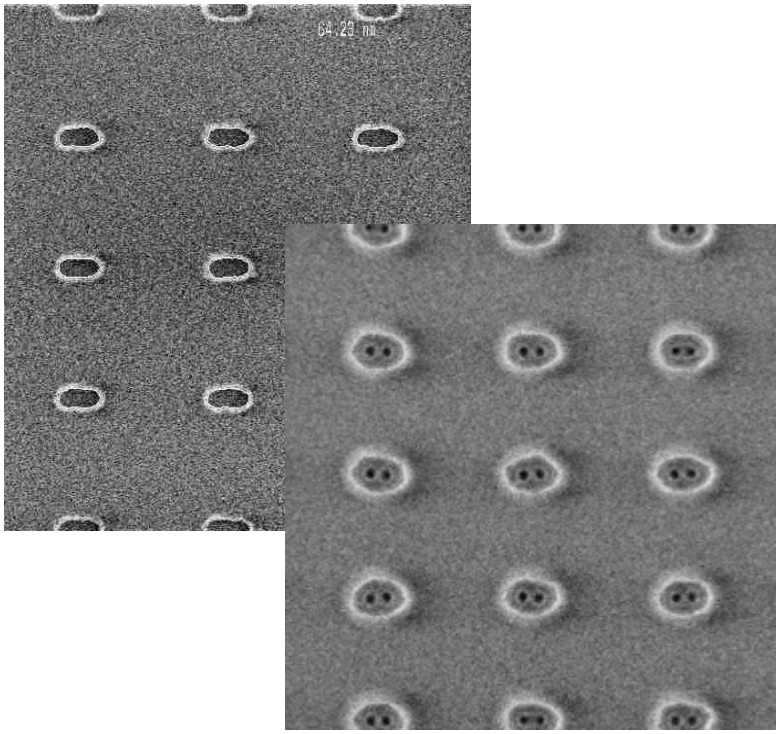
After litho

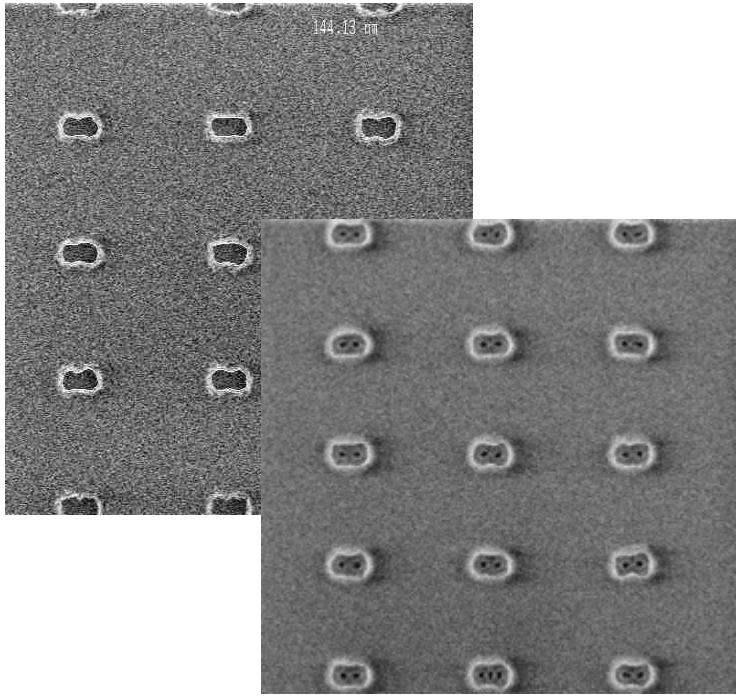



After etch into SOG/SOC

# TEMPLATED PROCESS

## 2-HOLE FEATURES





Very strong correlation between pre-pattern quality and position accuracy, open CH rate. The pre-pattern may require EUV resolution.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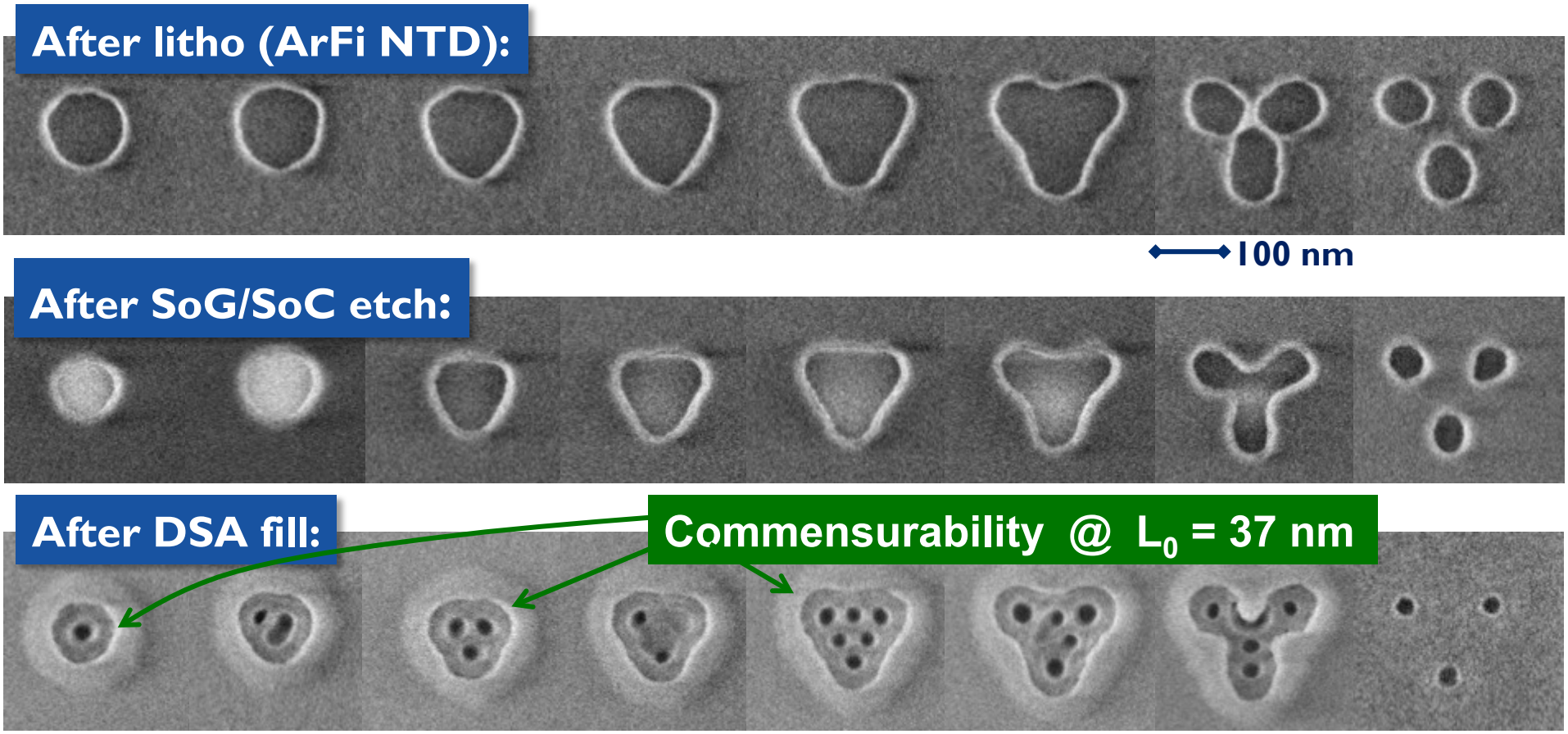
# TEMPLATED PROCESS

## IMPACT OF PRE-PATTERN QUALITY ON CONFINEMENT




Very strong correlation between pre-pattern quality and position accuracy, open CH rate. The pre-pattern may require EUV resolution.

# OUTLINE

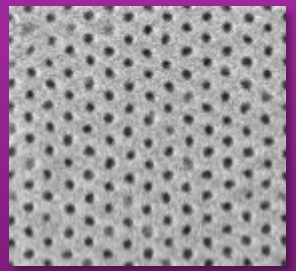
Introduction

Contact Hole Shrink (grapho-epitaxy)

Templated DSA (grapho-epitaxy)

Honeycomb Process (chemo-epitaxy)

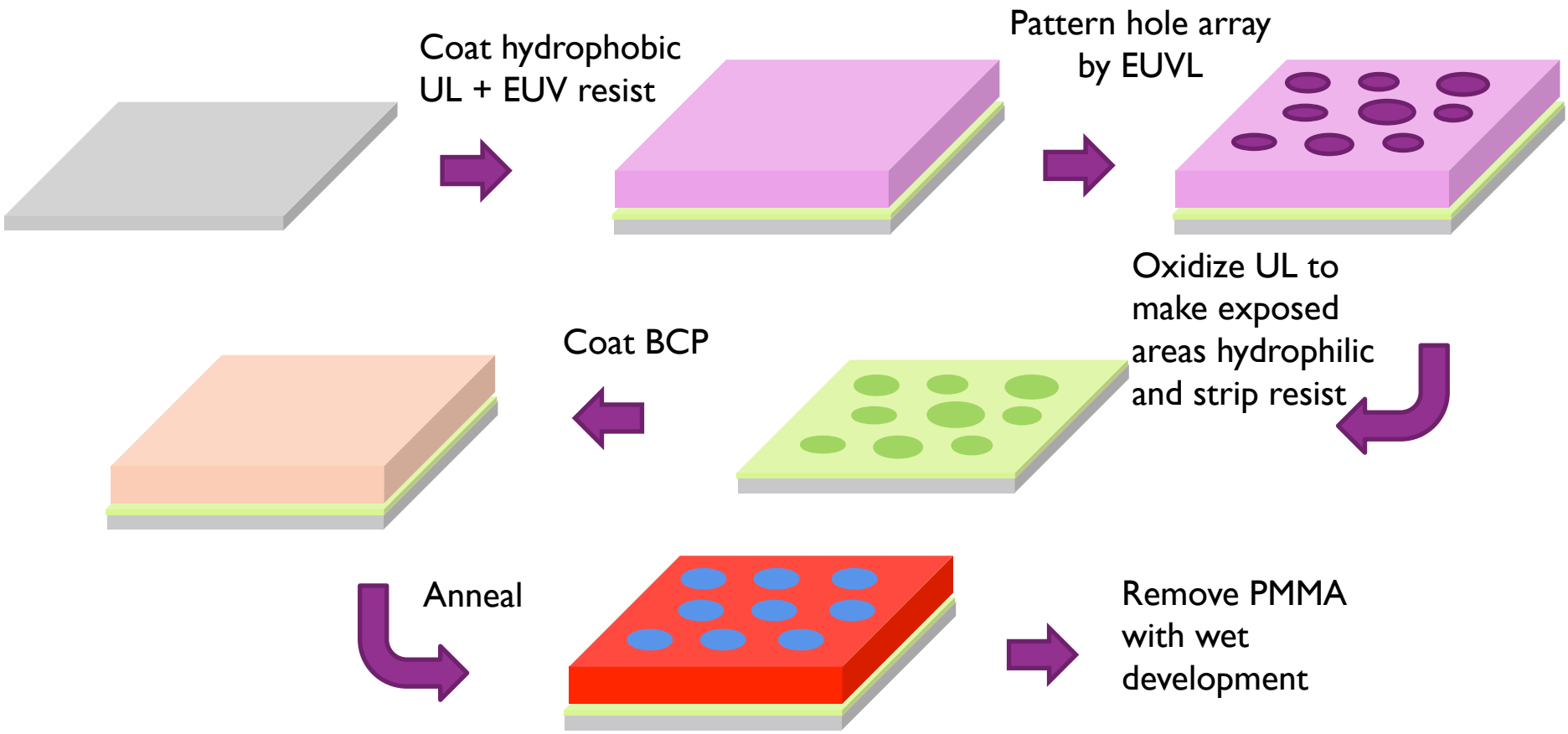
- Dense hexagonal array patterning



Summary

# HONEYCOMB PROCESS

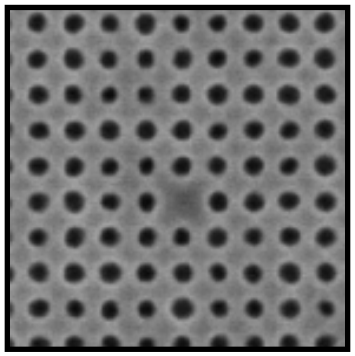
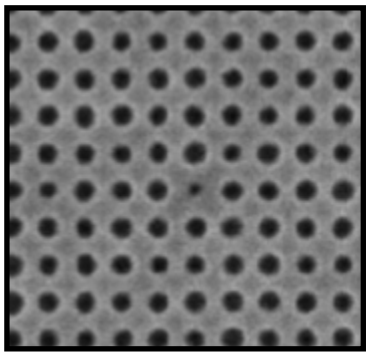
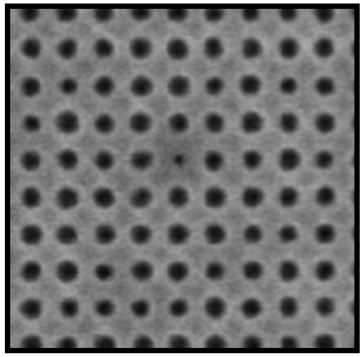
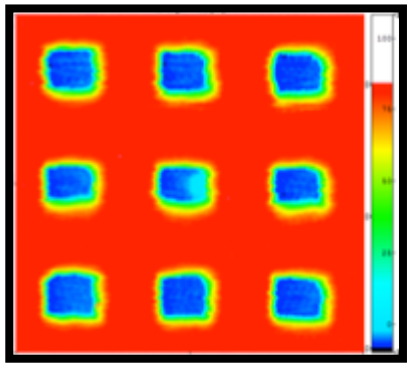
## CHEMO-EPITAXY CH FLOW




This process can be used of contact hole healing, missing contact hole repair and contact hole multiplication.

# CLOSED CONTACT HOLES IN EUV

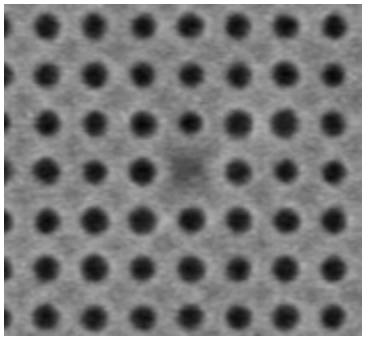
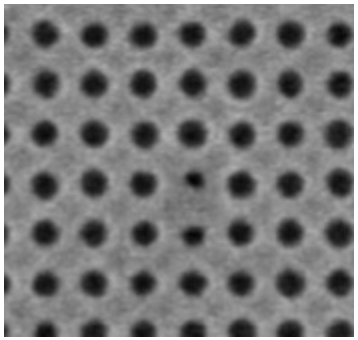
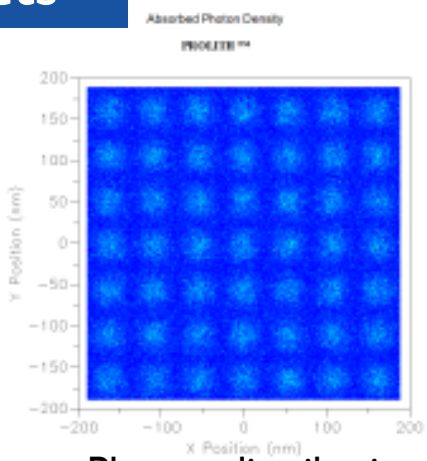
## Multilayer blank defects

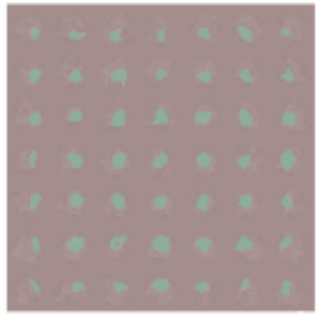





30nm hp contacts printed with NXE:3100

Mask review with AFM

## EUV variability due to stochastic effects



30nm hp contacts at 20mJ/cm2

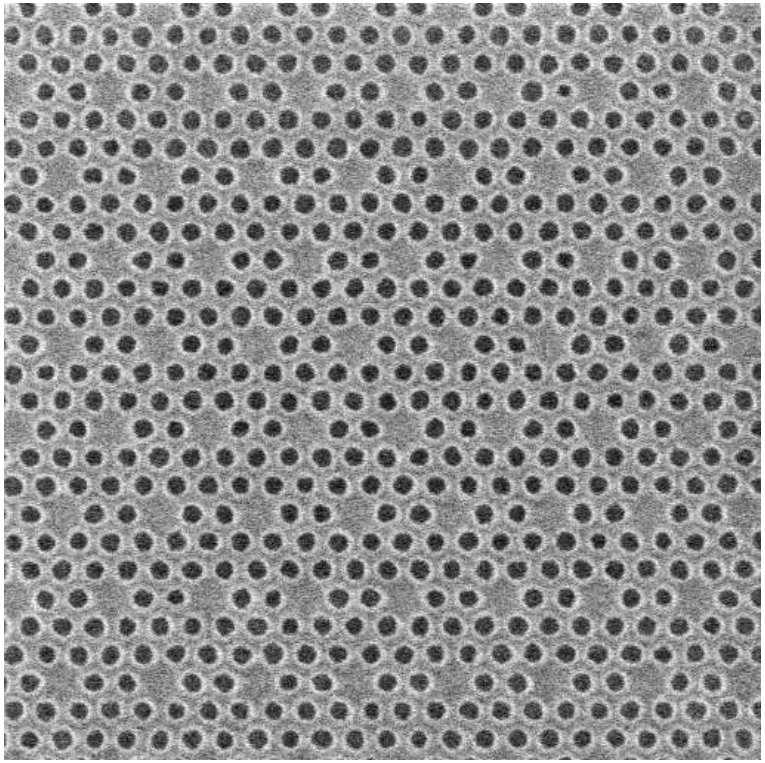
Photon distribution

Resist profile

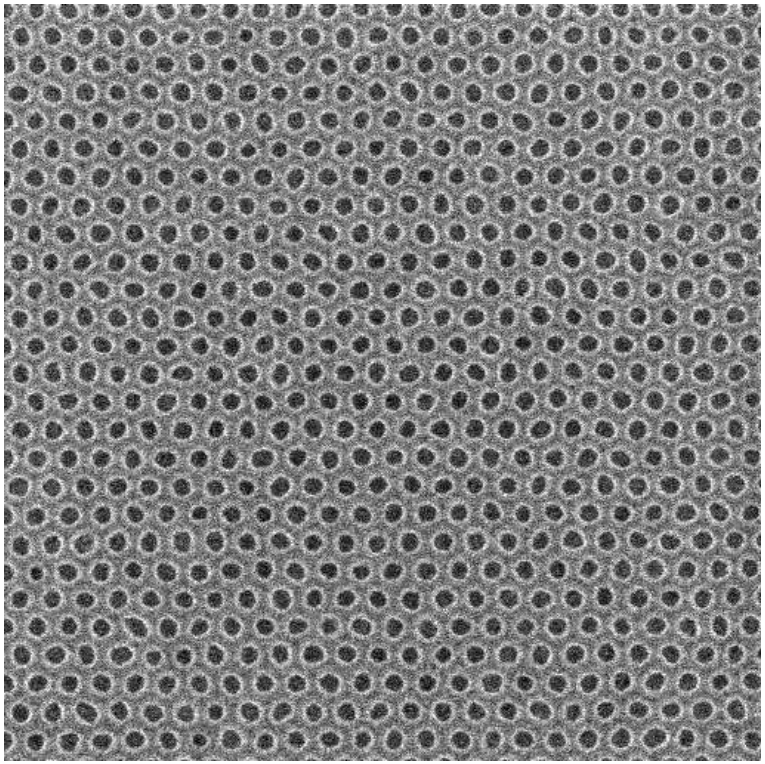
# HONEYCOMB PROCESS

## MISSING HOLE REPAIR VIA 1:1 PATTERNING

Pitch 58 nm



EUVL pre-pattern



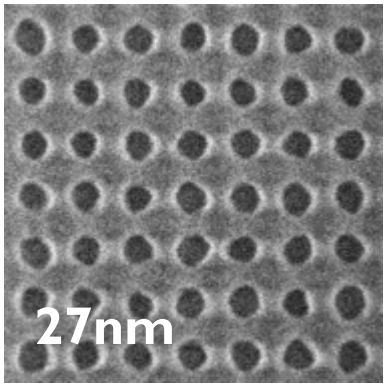
Post DSA of BCP A

The ability of our flow to repair missing holes in an EUV pre-pattern is demonstrated, and could help solving the ML defect/variability issues.

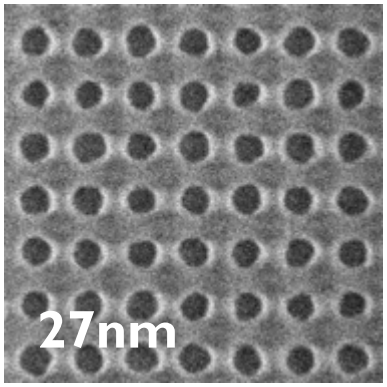
# LOCAL CD NON-UNIFORMITY

'fast resist'

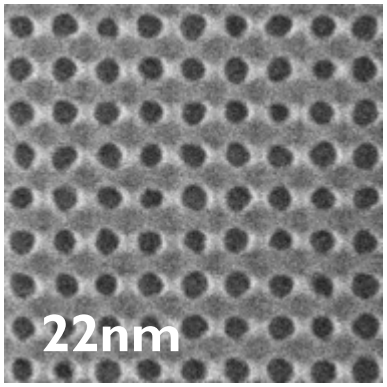
LCDU 1σ=1.9nm
DtS=25mJ/cm²




LCDU 1σ=1.4nm
DtS=22mJ/cm²

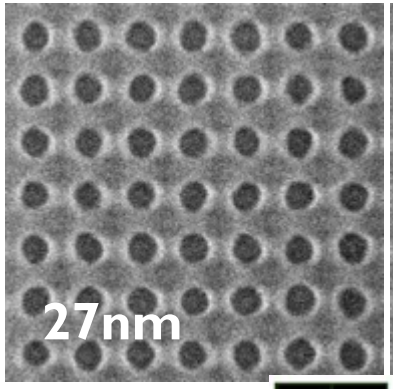



LCDU 1σ=1.7nm
DtS=22mJ/cm²



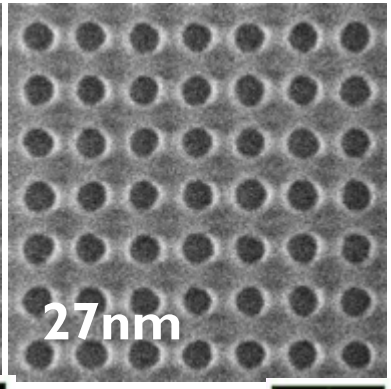

'slow resist'

LCDU 1σ=1.3nm
DtS=68mJ/cm²

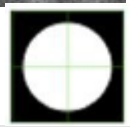



0.25NA

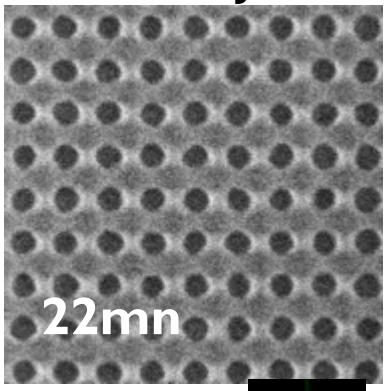
LCDU 1σ=0.9nm
DtS=56mJ/cm²



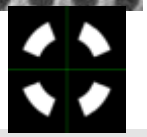

0.33NA



LCDU 1σ=1.0nm
DtS=53mJ/cm²

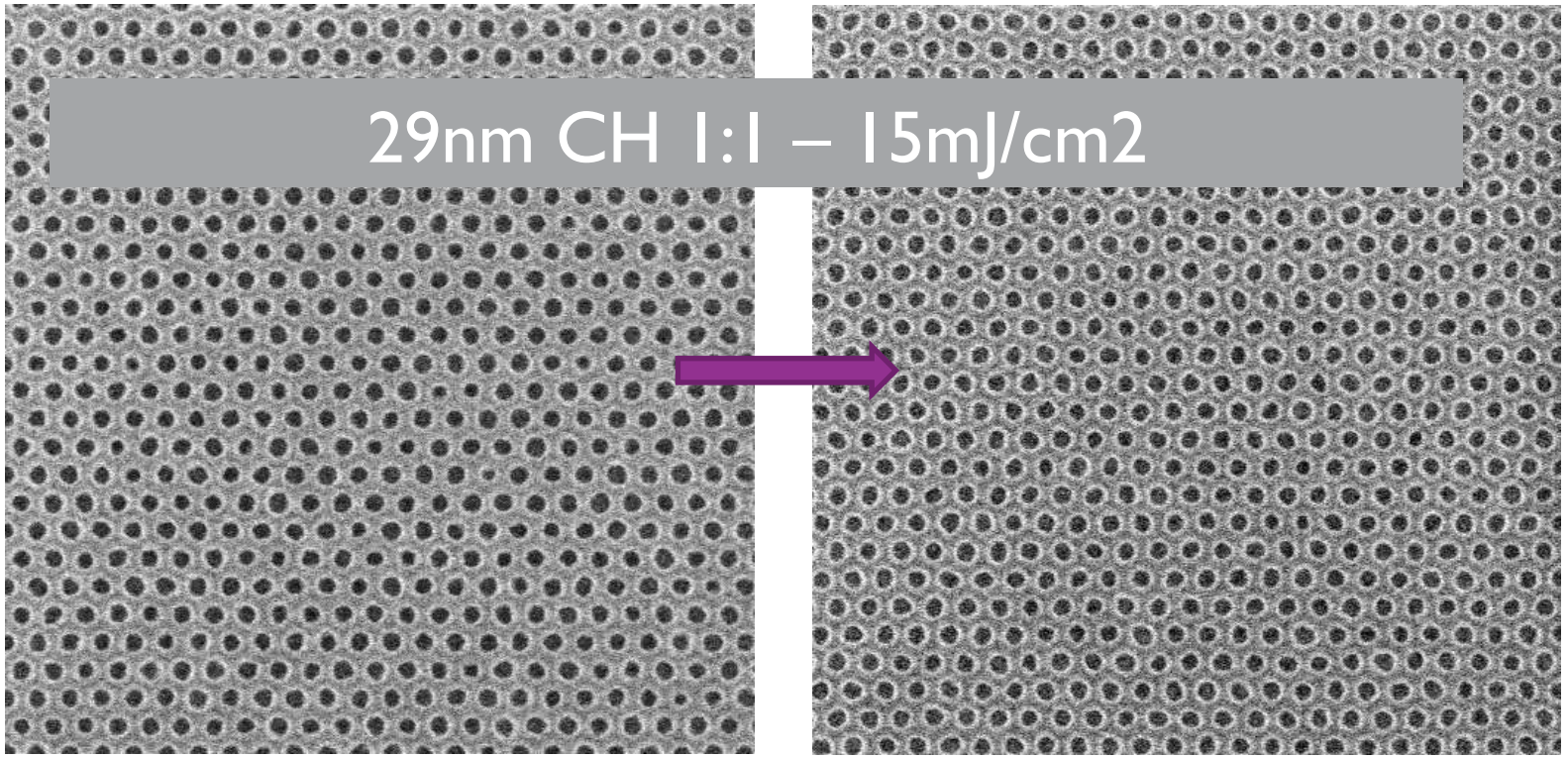



0.33NA



# LCDU REPAIR VIA 1:1 PATTERNING

## ENABLING LOW DOSE EUV RESISTS




EUVL pre-pattern
1 σ LCDU = 2.3 – 2.4nm

Post DSA of BCP
1 σ LCDU = 1.4 – 1.5nm

LCDU of DSA patterns largely depends on the BCP quality. We expect the post-DSA LCDU to improve as we transition to BCPs with sub-50nm pitch (NXE:3300). DSA may enable working with a higher LCDU EUV pre-pattern (ie fast resist!).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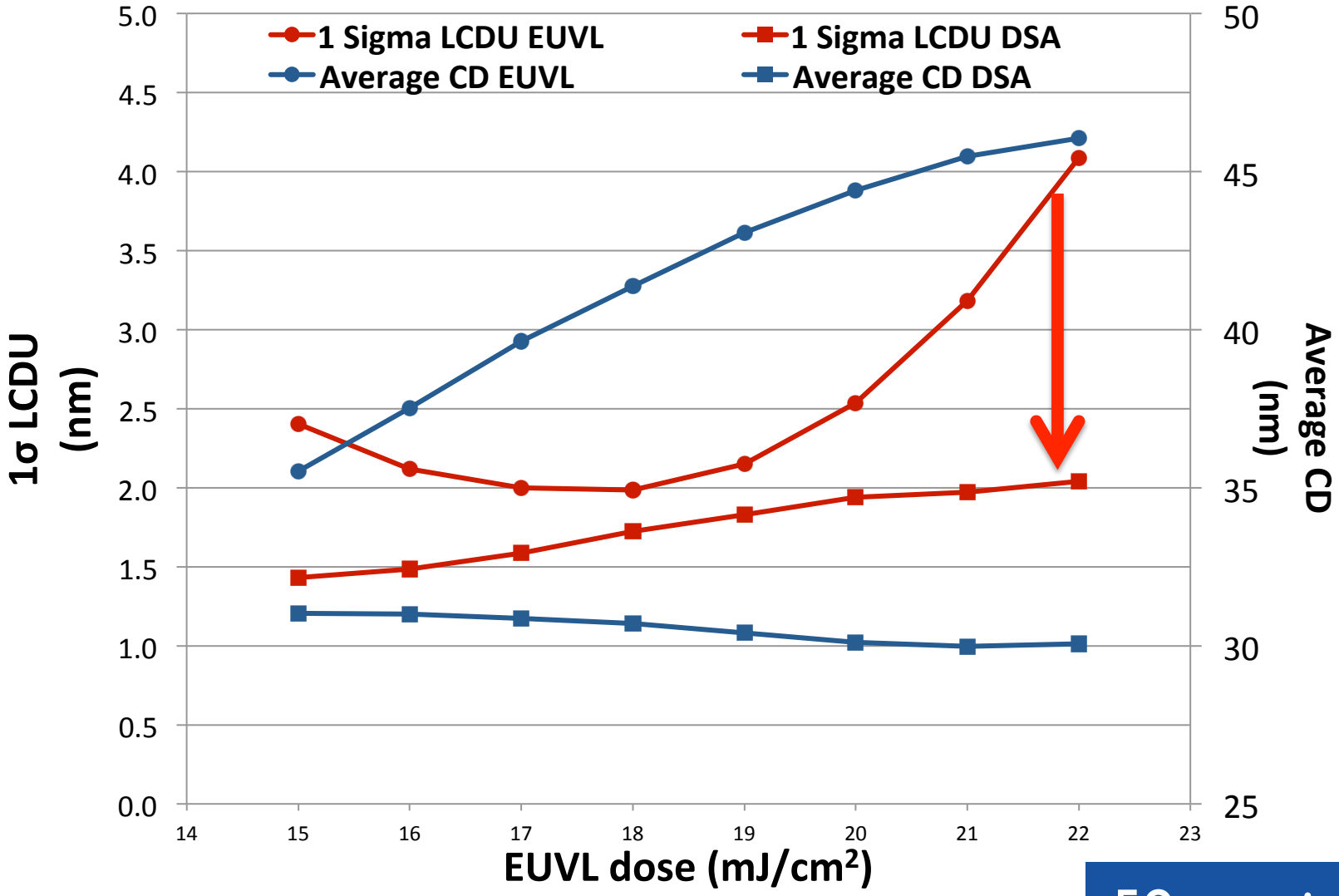
# LCDU REPAIR CONTD.

## UP TO 50% LCDU IMPROVEMENT




58nm pitch CH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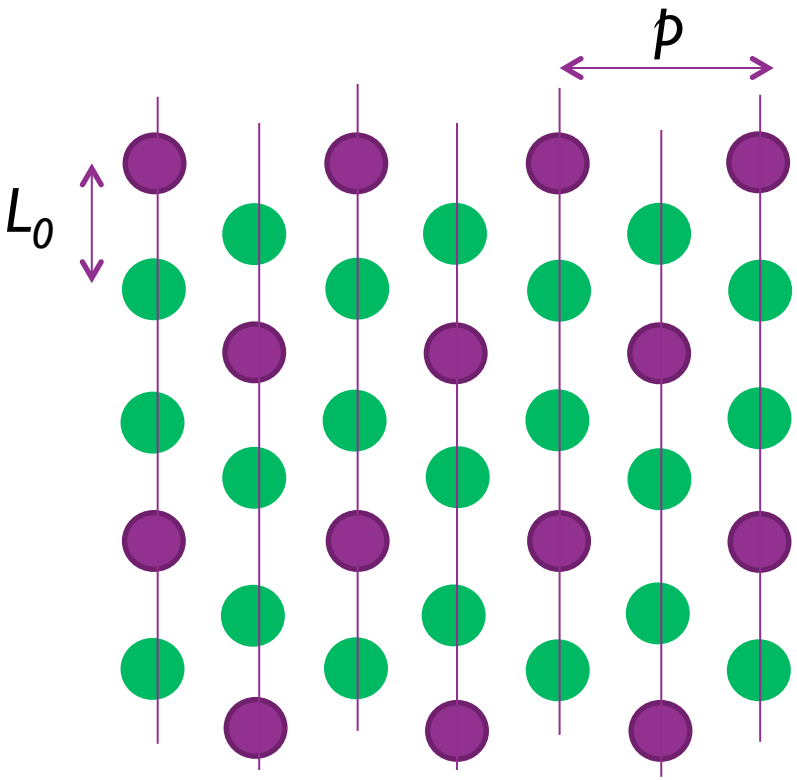
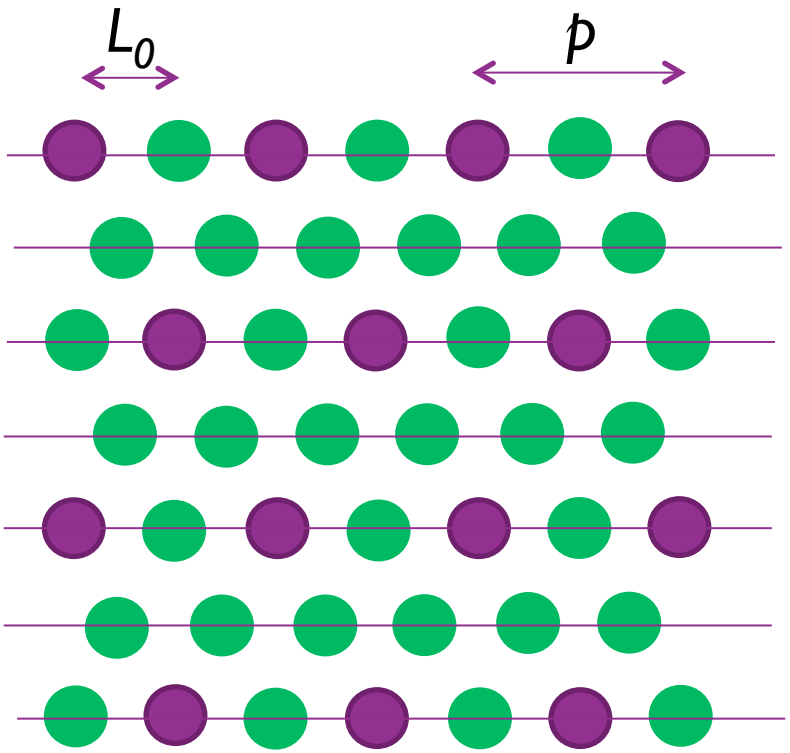
# FREQ. MULTIPLICATION SCHEMES




3x frequency multiplication

$L_0 = p/\sqrt{3}$

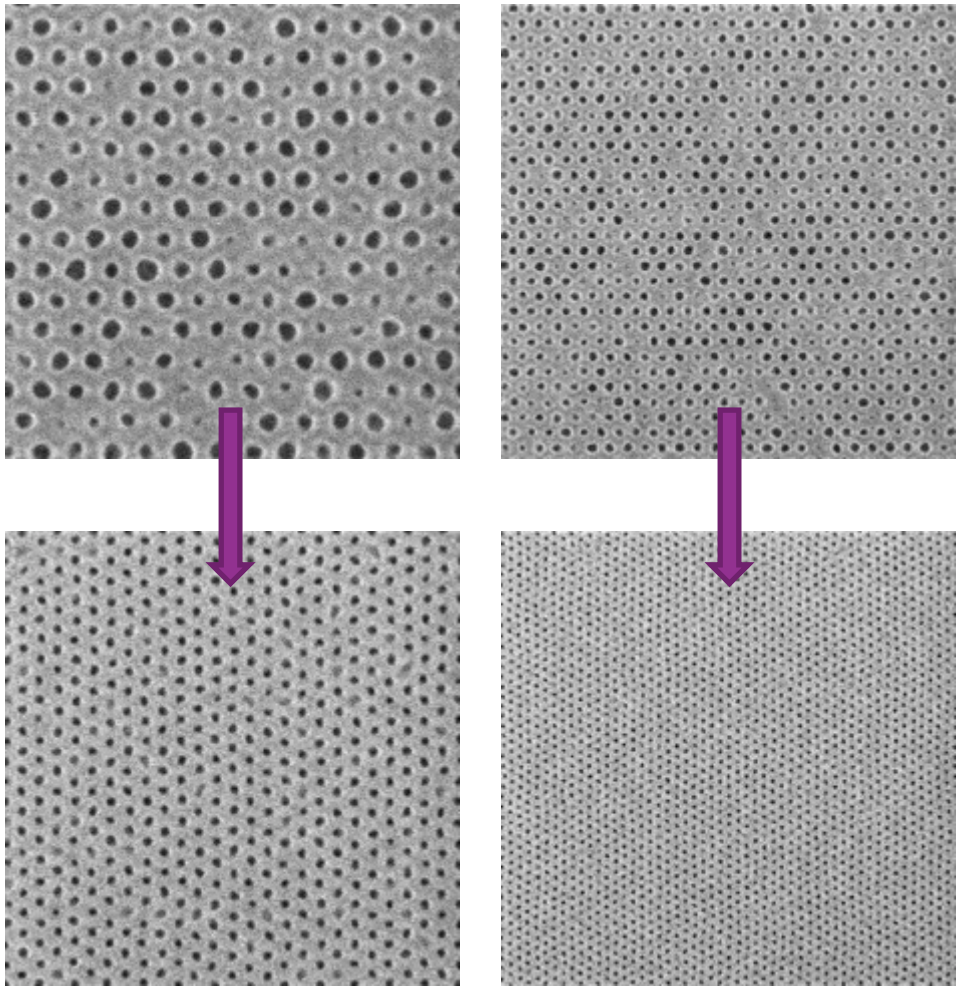



4x frequency multiplication

$L_0 = p/2$

For $L_0$ = 30nm we need 52nm pitch pre-pattern for 3x and 60nm pitch for 4x frequency multiplication

# 3X FREQUENCY MULTIPLICATION



200k mag

100k mag

**Post litho**

Pitch 52 nm
17 mJ/cm$^2$

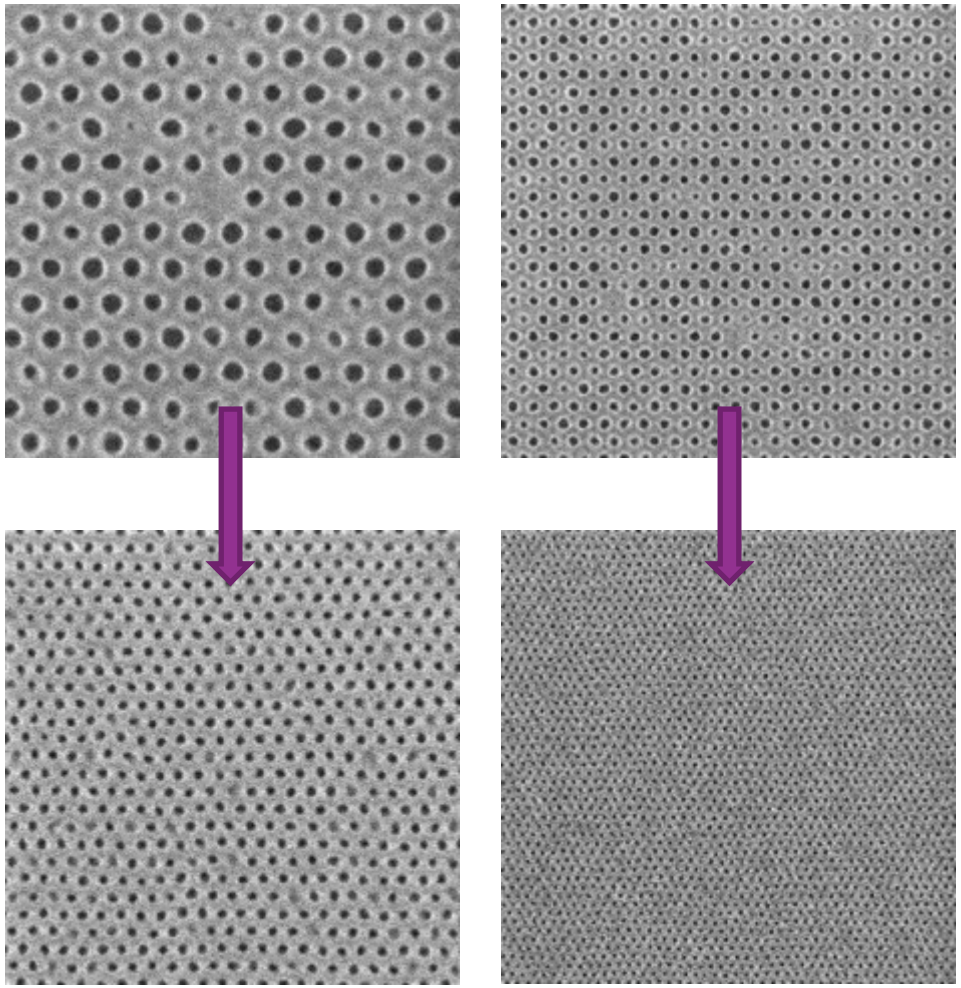
24 nm Average CD
> 4 nm 1 $\sigma$ LCDU

**Post DSA**

Pitch 30 nm

13 nm Average CD
< 0.5 nm 1 $\sigma$ LCDU

# 4X FREQUENCY MULTIPLICATION



200k mag

100k mag

**Post Litho**

Pitch 60 nm
16 mJ/cm$^2$

27 nm Average CD
> 3 nm 1 $\sigma$ LCDU

**Post DSA**

Pitch 30 nm

13 nm Average CD
< 0.5 nm 1 $\sigma$ LCDU

# OUTLINE

Introduction

Contact Hole Shrink (grapho-epitaxy)

Templated DSA (grapho-epitaxy)

Honeycomb Process (chemo-epitaxy)

Summary

# SUMMARY

Very good progress in materials/process

- DSA truly made it from the lab to the fab
- Focus now is on increasing process window by neutral layer material and etch process optimization

DSA as a **competitor**

- DSA can achieve EUV resolution starting from ArF(i) guide patterns

DSA as a **complementary technique**

- Pre-pattern quality of EUV lithography seems mandatory to guarantee pattern placement in the templated process (better confinement)
- DSA can clearly play a role in rectifying/healing the EUV resist image

DSA as an **enabler** for EUV lithography

- Low LCDU can be achieved using a fast resist and DSA, which could be key enabler for EUV

# ACKNOWLEDGEMENTS


Material Suppliers

- AZ-EM
- JSR
- TOK

TEL etch and Clean Track

- Doni Parnell, Ainhoa Romo Negreira, Mark Somervell, Kathleen Nafus